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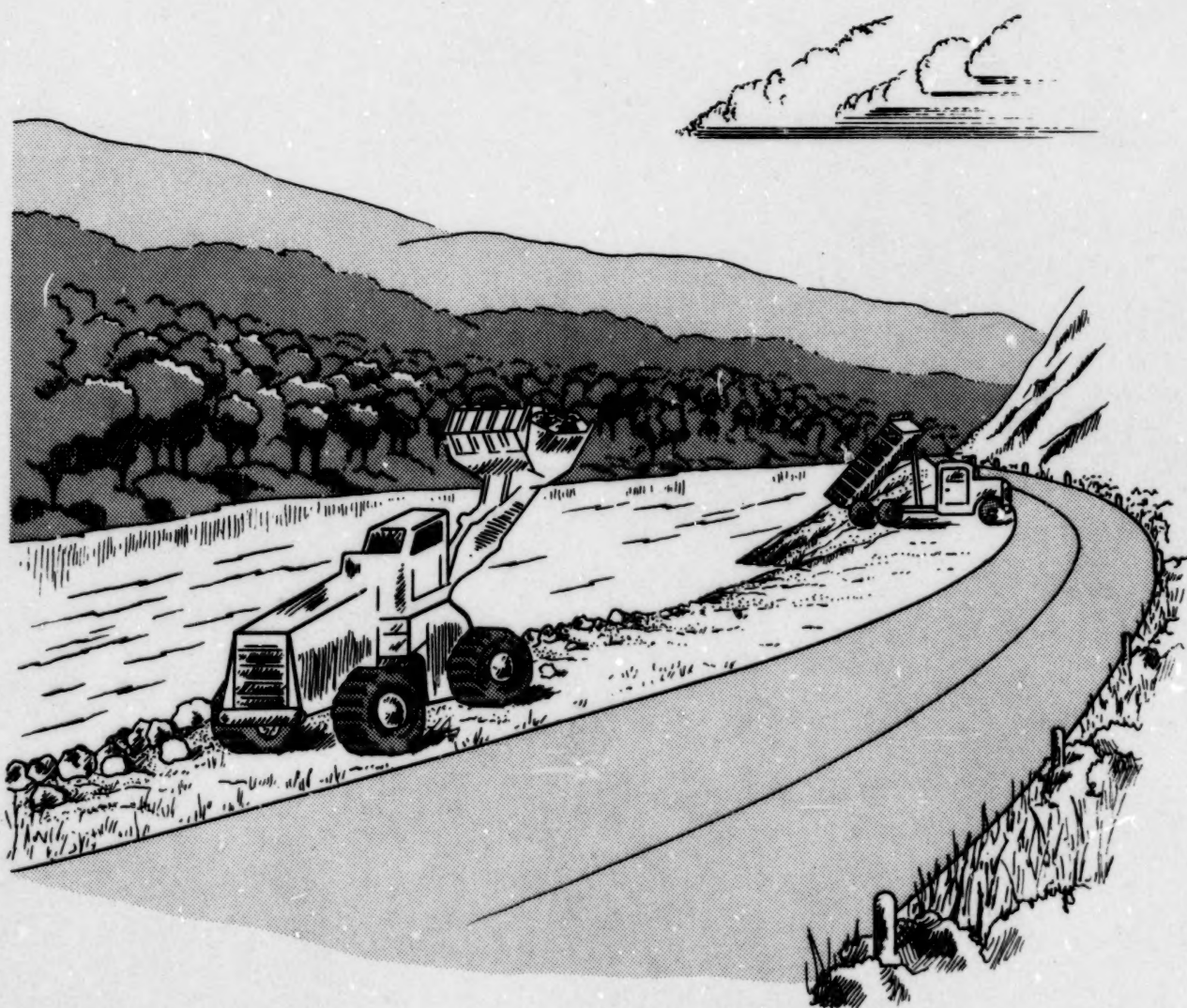
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IDENTIFICATION OF INSTREAM HAZARDS TO TROUT HABITAT QUALITY IN WYOMING



Fish and Wildlife Service

In cooperation with
Wyoming Game and Fish Department

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IDENTIFICATION OF INSTREAM HAZARDS TO
TROUT HABITAT QUALITY IN WYOMING

by

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SUMMARY

This paper presents definitions, lists consequences, and discusses interpretative keys for the identification of ten instream hazards to trout habitat quality: gully erosion; bank erosion; channel degradation; channel aggradation; pattern migration; pattern change; debris; pollution; flow regulation; and channel alterations. Physical processes and areas of susceptibility are described for six of these hazards but are inappropriate for debris, pollution, flow regulation and channel alteration. A procedure utilizing color infrared aerial photography for hazard detection and some workable techniques for mitigating certain hazardous conditions are also included.

The purpose of this report is to acquaint fisheries managers, land management personnel, landowners, naturalists, and others who may be involved in stream related activities with the common instream hazards to trout habitat quality in Wyoming. In addition, it is important to understand that hazardous conditions can be detected and remedied, at least in part, before irreparable damage to trout habitat quality has occurred.

Conclusions from this study are:

- o Bank erosion was the most prevalent of the ten hazards identified in Wyoming.

- o Hazards can be identified from color infrared aerial photography and verified by on-site visits.

- o Reaches with poor fish habitat can be improved through detailed design.

- o Hazards can lead to serious instability problems that affect water quality, stream condition, and streamside property, in addition to trout habitat quality. Thus, all users of streams systems and nearby lands are affected.

- o Site specific questions preclude formulation of a general cookbook approach to mitigating individual problems. Interdisciplinary approaches are recommended for mitigating individual problems.

- o Interpretative keys, mitigation techniques, and the hazards themselves are applicable to other western states, although the study was specific to Wyoming.

- o The general public should be made aware of the many hazardous conditions that exist and the irreparable damage to stream systems that can result from these hazards.

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INTRODUCTION

In this report, a hazard is defined as an activity of man or a natural process that may adversely affect trout habitat quality. Aquatic habitat quality is determined by a complex interaction of physical, chemical, and biological features. Quantification of all features responsible and their interactions is not practical for routine management purposes. Major determinants of trout habitat quality, however, can be defined with practical methods. Trout habitat quality has been related to nine habitat attributes (Binns and Eiserman 1979): (1) late summer stream flows; (2) annual stream flow variation; (3) water velocity; (4) trout cover; (5) stream width; (6) eroding stream banks; (7) stream substrate; (8) nitrate-nitrogen concentration; and (9) maximum summer stream temperature. Additionally, stream permanence, stream order, sinuosity, depth, gradient, pool:riffle ratio, discharge, turbidity, alkalinity, total dissolved solids, pH, phosphorous, chlorophyll, pollution, benthic invertebrates, stream side vegetation, and several other features have been identified as important trout habitat attributes. These attributes are susceptible to drastic modification through the activities of man or natural causes. Man's remedies to problems such as flooding and erosion often contribute to further habitat damage. Causes of habitat damage can be readily identified and often corrected with proper techniques. Patrick (1973) emphasized the importance of working in harmony with streams in the statement: "Man must remember that the stream and the flood plains have evolved over long periods of time, and have developed a system that is best for the natural conditions at hand. He should study it carefully and make sure that modification follows the dictums of nature."

Parts of this report are the direct result of photo-interpretation and field observations accomplished during the summer of 1981 on the Green, North and South Forks of the Shoshone, Shoshone, Big Horn, and Wind Rivers in Wyoming. The photo-interpretation work was performed using color infrared aerial photography that had been obtained during the summer and fall of 1980 on these rivers. Indirectly, a good deal of this report is also based on several years of experience with other major river systems within the State, as well as in Colorado and Montana. With the help of district fisheries biologists, many specific hazardous conditions were identified on the color infrared photography and verified by on-site visits to the various rivers during the summer of 1981. All of the observed hazardous conditions were reduced to ten general categories. Although all ten of the categories of hazardous conditions were identified in Wyoming, these hazards undoubtedly exist in other western states as well. Key indicators of these hazards and mitigating techniques should apply in other western states too.

HAZARDS

GULLY EROSION

Sheet, rill, and gully erosion are all known to occur on watershed surfaces (ASCE 1975). All three forms of erosion provide sediment to the stream. Oftentimes, magnitudes are large enough to cause stream aggradation and flow pattern change (Gregory 1977). Sheet erosion is defined as the wearing away of a thin layer of the land surface. Rill erosion is defined as the removal of soil by small concentrations of flowing water with a formation of channels that are small enough to be smoothed completely by normal cultivation methods. Gully erosion, however, may suddenly provide large quantities of sediment and is considered to be potentially more dangerous (Figure 1).

A gully has been defined as a recently extended drainage channel that transmits ephemeral flow, has steep sides, a steeply sloping or vertical headscarp, a base width of at least a foot and a depth of at least two feet. Gullies are widened, lengthened, and deepened mainly by scarp erosion (Brice 1966) (Figure 2). Critical slope represents one of the most important geomorphic thresholds for gully processes (Schumm 1977).

Physical Processes

The extension of the drainage net by headward migration and deepening of scarps or headcuts is the basic process by which the channel bed is lowered. The vertical face can be maintained if the material making up the bed above the headcut has a resistance to shear stress greater than the stress provided by the flow. Also, the flow has to be sufficient to transport the eroded material away from the base of the headcut. Undercutting the vertical headcut by plunge-pool action is presumably greatly aided by slumping of the moistened headwall after the storm flow ends. The rate and extent of local slumping and collapse in the hours following a storm flow or even on the day following a storm is very pronounced. The erosive action of water flowing over the vertical face of a gully head is not the most active cause of headward progression.

Many minor tributary valleys have been formed by headward erosion. The most common type of headward erosion is represented in the extension of a ravine by concentration of incoming sheet waters with a tendency to weathering and slumping at the ravine head, as described above. A second type of headward erosion is affected by spring sapping. This takes place when a spring emerges at the head of a valley or meadow. The overlying material is undermined by solution, and the weathering and the subsequent slumping above the spring may produce an abrupt scarp (Thornbury 1969).



Figure 1. Gully outwash (center) can suddenly provide large quantities of sediment to the receiving stream (Wind River near Dubois, Wyoming).



Figure 2. Valley bottom gullies (after Brice 1966).

A process similar to gully erosion occurs on the faces of terraces or benches along river systems and is defined as a gulch. Ephemeral or intermittent flows may erode a very distinct trough out of the terrace or bench face and deposit the material in the form of a fan at the toe of the terrace scarp (Figure 3). The resulting fan material may subsequently be transported and redeposited downstream when the stream encroaches upon the fan. Such erosion activity and the extent of the deposition zone are clearly identifiable on aerial photography.

Area of Susceptibility

Steep-sided valleys that drain areas of cultivated upland are most susceptible to gully erosion. In most cases, active gully erosion is attributed to land use, over-grazing, and cultivation, leading to concentration of runoff onto poorly vegetated areas. Drought conditions may also be a factor in initiating gullying (Brice 1966). Active gully erosion has been linked to more extensive downstream flooding (Gregory 1977). The gullying process is dominant in arid and semiarid regions. Changes in runoff characteristics are manifested by drainage network changes and where the influence of man has been substantial or rapid or both (Gregory and Walling 1973).

Consequences

Deposition of eroded sediments downstream is the general consequence of gully erosion. These deposits tend to plug the channel, reduce capacity through bridgeways and, in some instances, alter the pattern or the flow of the stream. Increased flooding can arise because of the decrease of channel capacity. Decreased water and sediment transport capacity can occur as a result of pattern change.

Sediment deposition severely degrades trout habitat. Armour (1977) summarized numerous documented adverse effects of sediments on trout populations and habitat. Sediments settling on substrate gravels interfere with intergravel water flows. This prevents developing trout embryos from receiving adequate dissolved oxygen for metabolism and water to flush away metabolic wastes. Inverse relationships have been documented between concentrations of fine sediments and the survival of trout embryos (Peters 1962). Deposition of sediments after salmonid embryos have hatched can prevent them from moving into the stream from the gravels (Lantz 1971).

Serious degradation of aquatic habitat in the North Platte River resulted from heavy silt loads (McDonald and McKnight 1977). Confined trout subjected to the heavy silt loads suffered inflammation around their respiratory and feeding parts. Game fishes appeared to migrate from the area in an avoidance reaction. An immediate reduction in benthos diversity, equitability, and abundance occurred following the heavy silt load. Numbers



Figure 3. Gulch erosion from ephemeral flow deposits sediments at the toe of the terrace scarp (Green River near Fontenelle, Wyoming).

of benthic invertebrates which provide food for trout have been reduced as a result of sedimentation in numerous other Wyoming streams (Oberholtzer 1969; Connell 1978).

Identification/Photo-interpretation

The photo-interpretation of gullying utilizes the basic concepts of size, shape, shadow, tone and color, pattern, and association. The gullies are generally fairly good sized processes and identifiable even on small scale aerial photography. They can, however, be very extensive in size where the floor of the gully may be several tens of feet wide and the walls may be ten to twenty feet high. The cross sections are characteristically U-shaped, rectangular-shaped, or V-shaped, depending on the type of material they are eroded into. The plan and profile are also unique to the eroded material (Figure 4). Gullies cast unique shadow forms at low sun angles. Oftentimes, the walls of the gully are light-colored and the lack of vegetative cover about the perimeter of the gully is characteristic. A planimetric pattern is unique and well defined. Gullies are often associated with upland areas on first order channels. Overgrazing and cultivation, particularly in arid and semiarid regions, may be a most obvious photo-interpretation key. Vegetation may develop in the bottom of the gullies where some water accumulates. Characteristic pools of water may sometimes be found in the plunge pool regions at the upper end of the gully. Infrared aerial photography has been shown to be most valuable for detecting small channels and for the delineation of small drainage basins of the headwater type (Parry and Turner 1971).

Repeated aerial surveys are valuable for documenting the development and progress of this erosion phenomenon. In addition to aerial photographs, topographic maps, surficial geology maps, and soils maps are useful for delineating areas susceptible to gully erosion. On-site visits to suspect areas should be made to confirm evidence of localized tendencies for gully development.

BANK EROSION

Active bank erosion resulting from recent lateral migration or direct impingement of the major flow path of a stream represents an imminent threat to the local and overall stream system equilibrium. Unless remedial measures are taken immediately, irreparable damage may occur to the riparian vegetation and stream ecosystem.

Physical Processes

Minor variations in sediment type and strength within the banks produce different changes in profile form and appear to affect the method of bank

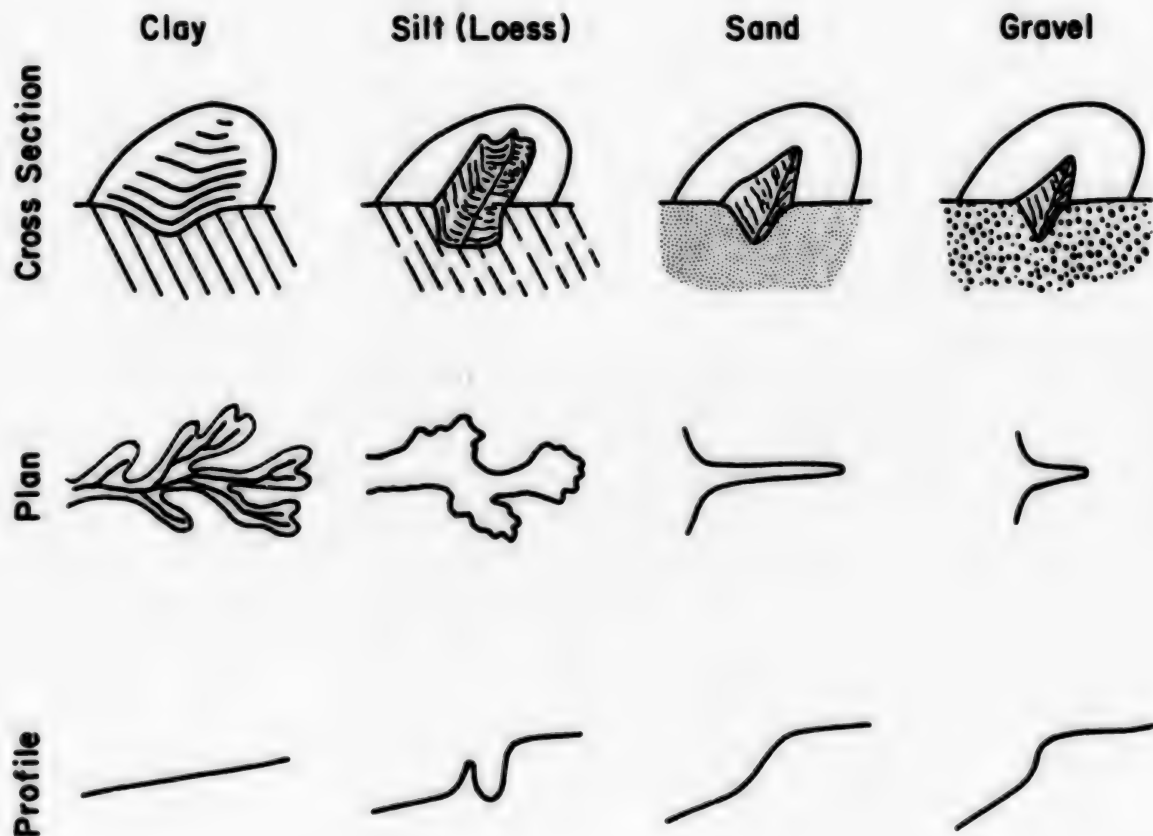


Figure 4. Cross-section, plan and profile for gullies (after Colorado Department of Highways 1962).

retreat. Four possible mechanisms operate in bank erosion: vertical retreat; basal scouring and undermining; collapse of overhanging blocks; and rotational slipping (Gregory 1977).

Erosion is a comprehensive term applied to the various ways by which water and wind obtain and remove rock debris (Thornbury 1969). The erosive power of flowing water on a channel bank is determined primarily by the local shear stress or drag exerted by the flow on the boundary and by the associated velocities and fluctuations of velocity near the boundary. Macro-turbulent flow phenomena, such as eddies, helicoidal flow (flow path in the bend way in the form of a helix or spiral), rollers, and surges, may also be important factors influencing scour. The resistance to erosion of cohesionless bank materials depends primarily on grain size, size distribution, grain density, and to a lesser extent, grain shape, orientation, and packing arrangement (Neill 1973).

Nature provides endless opportunities for initiation of bank erosion. Such things as chance emplacement of a boulder, a fallen tree, or changes in flow regime may be the triggering mechanism (Leopold et al. 1964). Some observers have pointed out the fact that almost any obstruction in the bed can cause the current to be deflected into a bank; or the obstruction might erode an irregularity that, in turn, can deflect the current to the bank, thus establishing a chain reaction (ASCE 1975).

Stream bank erosion is often occasioned by the clearing of protective cover from banks and from channel straightening and realignment measures, which affect the flow through changes in slope and stream competence (ASCE 1975).

Areas of Susceptibility

Areas of susceptibility for bank erosion include zones where small amounts of vegetative bank cover exist, particularly deep-rooted vegetation such as willows and trees (Figure 5). Fine, unconsolidated materials, such as silts and fine sands, or noncohesive materials of larger size with small amounts of binder are particularly susceptible to bank erosion. Reaches of bank where the flow is concentrated along the concave section or through a constriction almost invariably exhibit bank erosion problems. Flow path impingements caused by obstructions in the channel, bar developments, and hydraulic structures lead to severe bank erosion zones. Bank lines upstream and in the vicinity of recent neck cutoffs are particularly liable to rapid bank erosion.

The flow in a wide, shallow channel tends frequently to meander within the channel. Braided streams shift their position at random intervals, particularly during or following a rise in stage. As a result, the location of

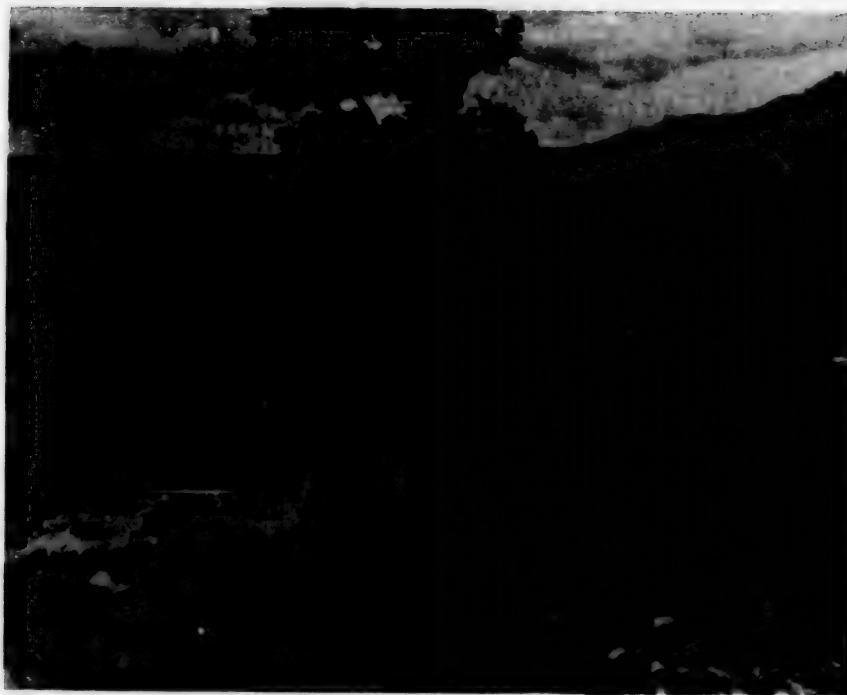


Figure 5. Deep-rooted, woody vegetation provides remarkable protection and trout habitat (South Fork Shoshone River, Wyoming).

bank erosion varies over time. Protection works placed in a stream may be entirely bypassed at a later date and the attack shifted to an unprotected location (ASCE 1975).

Consequences

Bank erosion impairs trout habitat through generation of sediments, direct reduction in stream length, alteration of hydraulic features, physical elimination of trout cover, and man's efforts to repair eroded banks. Severe bank erosion impairs trout growth, survival, and reproduction due to the massive quantities of sediments generated. Refer to the consequences of gully erosion for specific adverse fisheries effects of sedimentation.

Where bank erosion cuts off meanders, the length of available trout habitat is reduced. The resulting neck cutoff will have high water velocity and be lacking in habitat features favorable to trout. To compound these effects, higher velocities can trigger further erosion both upstream and downstream.

Trout cover provided by streambanks, streamside vegetation, and water depth are often reduced by bank erosion. Streambank features following erosion frequently consist of a nearly vertical bank devoid of vegetative types which provide good cover. Slump blocks can further reduce habitat at the base of the streambank. Stream width increases by severe lateral erosion can reduce trout cover available in the form of water depth. In extreme cases, depths may be insufficient for trout to even occupy the stream.

Property damage or the threat of property damage often accompanies severe bank erosion. Man's efforts to repair eroded banks are frequently improperly designed and constructed. This results in structures which may be ineffective, effective but requiring frequent maintenance, or effective but not in harmony with the stream. Ineffective structures and those requiring frequent maintenance result in additional instream construction activity to the detriment of trout habitat. Structures not in harmony with the stream cause further streambank erosion to other property owners above and below the protected area. Landowners have passed erosion problems on to their neighbors in this manner on numerous Wyoming streams. Proper planning and construction is vital if repair of eroded stream banks is to be successful and free of serious adverse effects on neighboring property and trout habitat.

Identification/Photo-interpretation

Primary indicators of potential bank erosion sites include lack of vegetation on bank lines, concentration of high velocity flow adjacent to the bank, and deflected flow paths caused by local obstructions in the

channel, including fallen trees, boulders, bar deposits, and hydraulic structures. The eroding bank areas demonstrate tipping and fallen vegetation adjacent to the outer bank, cracks along the bank surface, slump blocks, fresh vegetation laying in the flow, deflected flow patterns adjacent to the bank line, increased turbidity in the water, fresh vertical or sloping face cuts, new deposition in the form of bars immediately downstream from the eroding area and, in some instances, a deep scour pool adjacent to the toe of the bank slope (Figure 6). High cut banks form where currents strike and undercut steep, unconsolidated hill slopes (Figure 7).

Bank erosion can be prompted by areas of ground water seepage. During the process of seepage, the flowing water exerts a force upon the soil particles which helps in the deformation process. This can represent a special type of water erosion or it can act in conjunction with the flowing water (Scheidegger 1969) (Figure 8). Thermal infrared imagery has been used to locate ground water inflow along selected reaches of rivers (Skinner and Ruff 1973; Boettcher et al. 1976).

Color infrared aerial photography is particularly useful for noting most of the bank erosion indicators listed above. The majority of suspended material being transported by a river is obtained from the bed and banks of the river and its tributaries (Ruff et al. 1973). Differences in turbidity manifested by suspended material concentration variation is particularly noticeable on color infrared photography. In addition, both color and color infrared photography have demonstrated their utility for identifying bank material, stability, and form (Skinner 1978).

The rate of bank retreat can be readily estimated by comparing large-scale, multidate photography. Sequential aerial photography is an excellent tool for recording long term trends in shoreline changes and for studying shoreline features. Photogrammetric procedures may be utilized to determine volumes of eroded material. Basic studies show that color infrared photography generally is superior for species identification, plant vigor measurements, and vegetation mapping (Jones 1977). Lateral erosion rates of several Alaskan rivers were determined by comparing multidate photographs; brief on-site inspections utilizing a helicopter were valuable in interpretation of the aerial photographs (Brice 1971).

The most comprehensive qualitative characteristics of the banks are determined by stereoscopic examination and measurements from aerial photos. This can be carried out with considerably higher precision on photographs than on topographic maps (Kudritskii et al. 1956). A very rough estimate of bank heights may be found by observing the nature of the flood plain. The approximate height of the banks can be determined by comparing them to the height of known features located on the floodplain, such as shrubs, trees, and buildings. The inclination of the bank slope can be determined



Figure 6. Presence of tipping vegetation adjacent to the outer bank, fresh vegetation laying in the flow and deflected flow patterns adjacent to the bank line indicates bank erosion problems (North Fork Shoshone River, Wyoming).

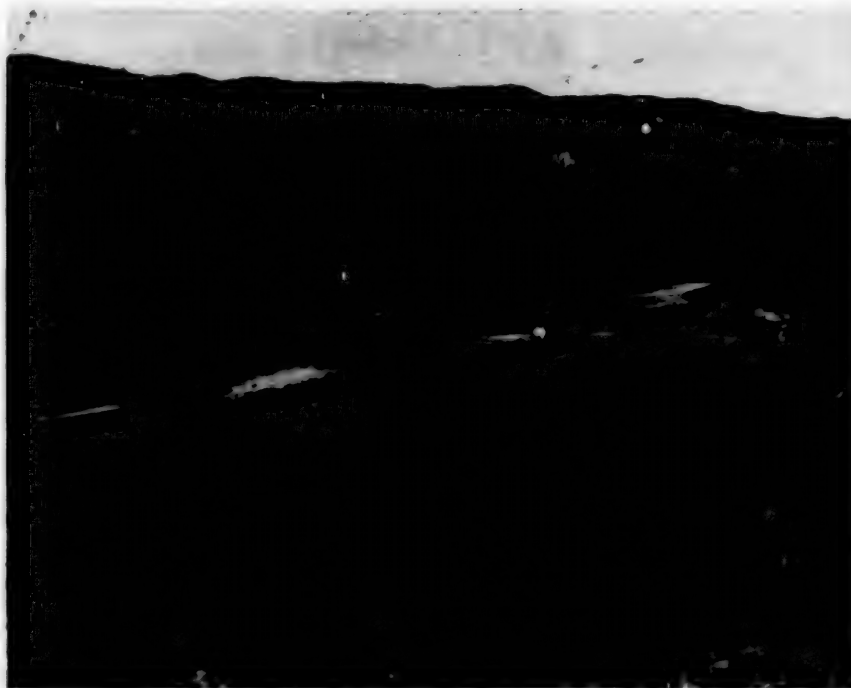


Figure 7. High cut banks form where currents strike and undercut steep, unconsolidated hill slopes (Wind River above Dubois, Wyoming).



Figure 8. Ground water seepage in conjunction with flowing water prompts bank erosion. Streambank collapse continues after high flows recede. (Green River near confluence with Big Sandy River, Wyoming).

qualitatively from shadows, vegetative cover, pattern of the slope's surface, soil composition of the valley floor, and the width of the visible part of the slope.

Photo interpretive keys of bank erosion conditions include vegetation, type and cover, saturated banks, varying width streams and bar deposition, fresh cut banks, parallel linear cracks along the top bank, leaning vegetation, bank slumping, flow concentration, and shadow, (Figure 9). Stable banks are associated with dense, deep-rooted vegetation. On the other hand, poorly vegetated banks, even in coarse, noncohesive material, may be very unstable (Figure 10). Bank erosion was one of the most commonly found hazards in this study.

CHANNEL DEGRADATION

A degrading channel is one in which a net loss of bed and/or bank materials is progressively occurring (ASCE 1975). The problem is essentially one of imbalance between the sediment load contributed to the channel and the ability of the flow to transport the load through the channel (Figure 11). A degrading channel may be eroding either vertically or horizontally, depending on the character of the materials in the bed and banks. Excessive bed slope in channelized sections may lead to rapid degradation, particularly during flood flows.

Localized scour and fill involves time measured in minutes, hours, days and perhaps even seasons; whereas aggradation and degradation occur over larger areas and apply to longer time periods, perhaps measured in years (Leopold et al. 1964). Localized scour and fill phenomena are often easy to identify utilizing photography from a single date. Degradation and aggradation, on the other hand, represent generally long term processes, and multirate photography over extended time periods is necessary to precisely determine the affected areas and relative magnitude of the degradation or aggradation.

Physical Processes

When the bed of a river channel is maintained at the same average elevation over a period of time because the inflow of the sediment to the reach equals the outflow, the river profile is said to be in equilibrium. This balance is determined by the ratio of sediment and water derived from the sediment basin, a function of rainfall runoff conditions, vegetation, and soil type. When a stream is capable of carrying away more sediment than is supplied to it, it carries away material from its bed and banks and thus tends to lower it (Frenette and Harvey 1973).

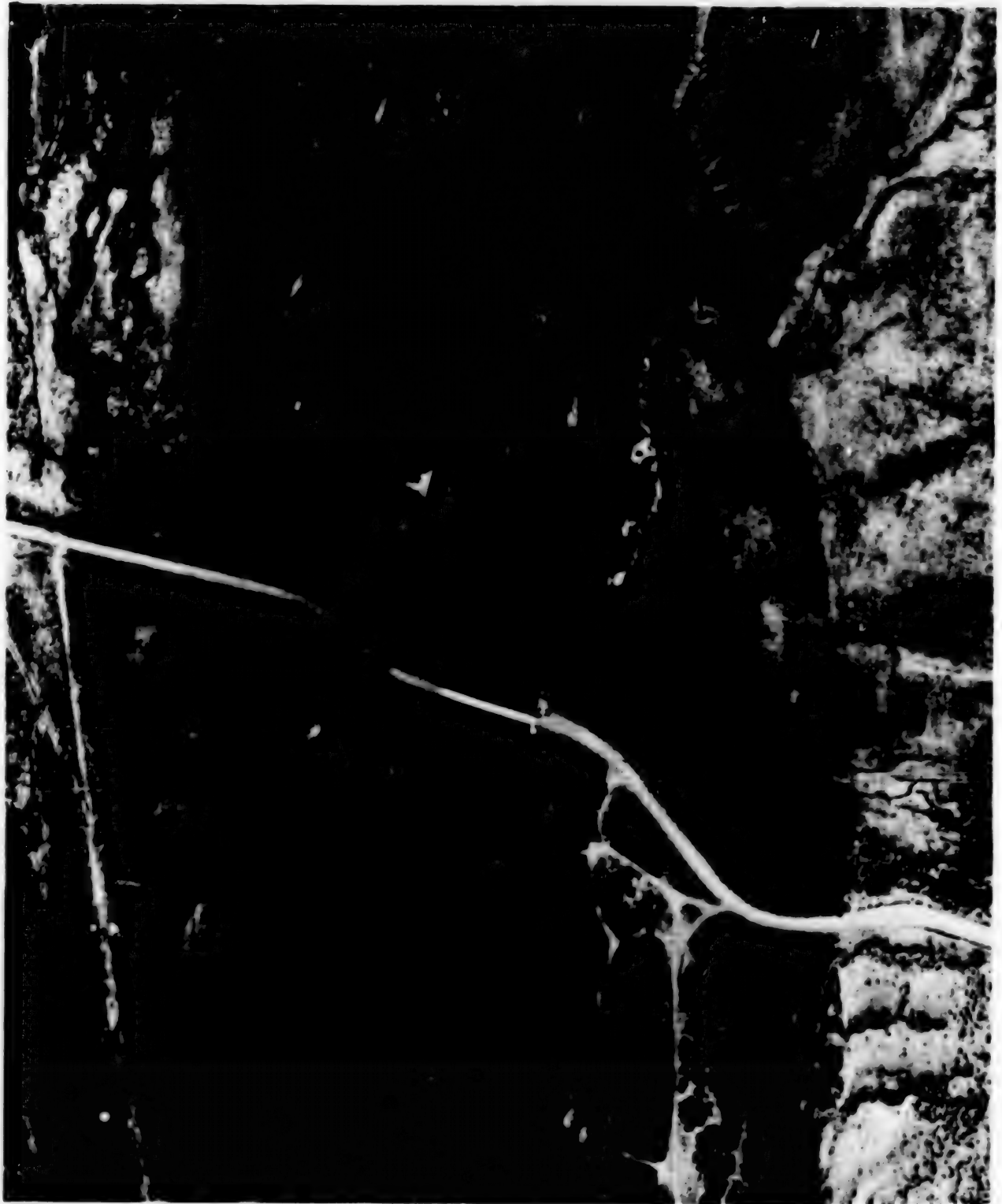


Figure 9. Shadows along streambanks provide a good photo interpretive key to bank erosion (North Fork Shoshone River near Wapiti, Wyoming).



Figure 10. Poorly vegetated banks, even in coarse, non-cohesive material, are unstable and subject to severe erosion (North Fork Shoshone River near Wapiti, Wyoming).

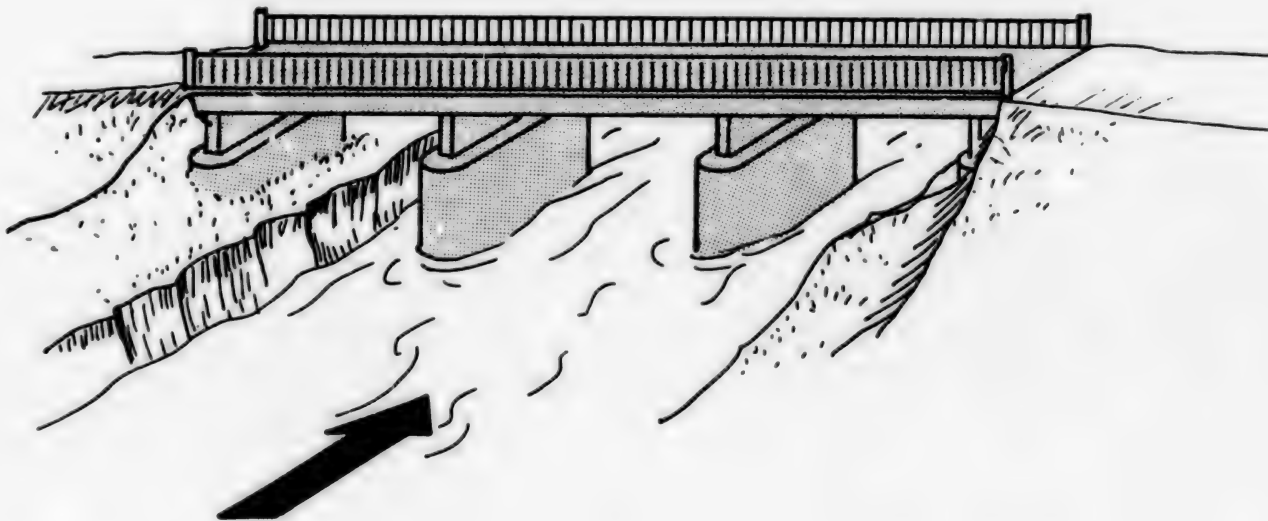


Figure 11. A degrading channel is evidenced by high banks and exposed lower parts of bridges and other fixed reference points.

Prolonged degradation and coarsening of the bed and bank sediments of streams can lead to armoring and to drastic reduction in the rate of degradation and sediment discharge (ASCE 1975). Bed armoring results from differential erosion leaving a layer of coarse material which forms an armor coat, thus preventing erosion of a finer fraction which lies beneath it. The development of an armoring bed is often a major factor in restricting degradation below dams (Gregory 1977). Whether bed armoring occurs or not depends on whether the sediment particles are of sufficient size to resist erosion. Fine, uniform size bed material cannot exhibit the armoring phenomenon.

Channel degradation, which includes stream bed and stream bank erosion, can be very significant under some circumstances. Accelerated stream bed erosion can cause the lowering of riparian ground water levels and, in water short areas, this drastically reduces the yield of such bottom land crops as corn and alfalfa. It can also trigger down-cutting cycles in tributary channels and gullying because of the lowering of the base level (ASCE 1975).

For eroding suspended load streams, the predominant erosion is stream bed erosion; for eroding mixed load streams, the initial erosion begins on the bed followed by channel widening; for eroding bed load streams, little stream bed erosion occurs and channel widening is predominant (Schumm 1977).

Areas of Susceptibility

In sand-bed rivers, bed levels respond rapidly to changes in discharge and scour holes formed by floods fill during falling stages. In coarse-bed material rivers, scour holes tend to persist through oscillating flow conditions perhaps even when the original causes have disappeared (Neill 1973). Causes of degradation include geologic uplift, decrease in base level (Figure 12), sediment transport capacity of the river larger than the sediment load, and increase in discharge (Frenette and Harvey 1973).

Degradation generally occurs downstream of newly constructed diversion structures. Clear water released from the outlet of the storage structure has a high erosive capacity and generally scour takes place (Figure 13). The rate of river bed degradation is rapid in the beginning, but may become small as the new stable profile evolves. This stable profile can be reached with less degradation when armoring of the bed occurs. The armoring is a function of the gradation and size of the bed material and of the flow. Bed degradation may extend indefinitely downstream of the structure that causes it (Simons and Senturk 1977).



Figure 12. Decrease in base level occasioned by channel alterations downstream of the bridge site (Green River near Pinedale, Wyoming).

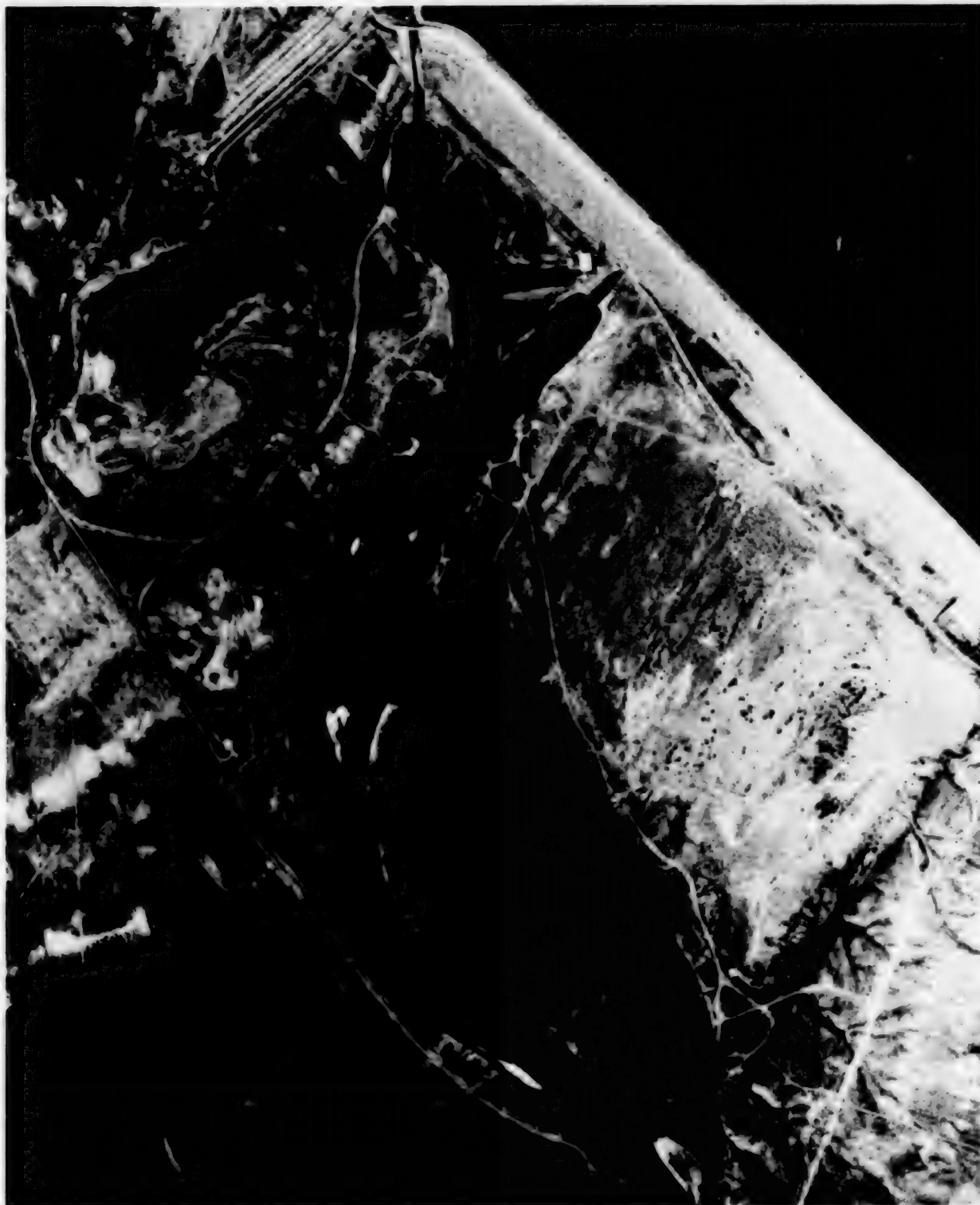


Figure 13. Channel degradation below reservoirs is discernible from aerial photography. Islands of streambed materials are visible downstream from sites of channel degradation (Green River at Fontenelle Dam, Wyoming).

Consequences

Degradation leads to bank caving and the undermining of hydraulic structures such as bridges; furthermore, in the natural stream channel, migration may become more violent and erratic (Parker and Andres 1976). Another serious problem is tributary headcutting and degradation. Where the stage is lowered on a channelized reach by bed degradation, the result is a lowered base level and an increase in the slope at the mouth of tributaries. The result is often extensive gullying and the loss of farm land for the entire range basin. Bridge foundations have been repeatedly undermined as a result of progressive channel profile degradation. Channel straightening often results in bed degradation and bank slumping upstream and in the vicinity of the modified section (Neill 1973).

Effects of channel degradation on trout habitat are not always immediately obvious due to the long term nature of this hazard. In general, the effects are primarily those previously presented for gully and bank erosion. Alteration of stream channel profile and hydraulic characteristics can also degrade trout habitat.

Identification/Photo-interpretation

Photo-interpretation can be used to judge whether a stream at a given site is actively degrading or aggrading its bed. Also, one can judge when it is likely that the effects of cutoffs, building of bridges, or pipeline crossings will scour the streambed (Mollard 1973). Multidate water penetration photography may be used in clear water conditions to determine the amount of degradation (Skinner 1978).

An entrenched channel is one having a channel bordered on either side by banks higher than the highest flood level. This type of channel is either actively degrading or has been doing so in the past (Gaylay et al. 1973). A persistent trend of raising or lowering of the stage-discharge curve indicates progressive channel aggradation or degradation, respectively (Neill 1973).

Quantitative estimates of channel degradation are obtained from timed sequence comparisons of surveyed cross sections, maps, aerial photographs, and historical records (ASCE 1975). Even in situations where quantitative methods of computation and the necessary data are available, results should be checked against geomorphological evidence such as may be contained in differences between the successive aerial photographs and maps, in plant growth successions, or in systematically shifting rating curves (Kellerhals et al. 1976).

CHANNEL AGGRADATION

By definition, progressive deposition both within the channel and on the flood plain is aggradation (Leopold et al. 1964) (Figure 14). An aggrading channel is one that tends to fill with sediments; again, the problem is essentially one of imbalance between the sediment load contributed to the channel and ability of the flow to transport the load through the channel (ASCE 1975). In an aggrading channel, restoration of the balance might be accomplished by either reducing the sediment inflow, increasing the transport capacity, or combining the two.

Physical Processes

Channel aggradation is generally a long term process existing over a fairly extensive reach of the river system. Localized filling, on the other hand, is generally a short term process and readily identifiable on single date aerial photography. Aggradation is slow at first and subject to periodic scour, but in time the deposits can become increasingly stable, vegetated, and able to collect more sediment. The channel losses by seepage then lead to reduced water velocities which further encourage greater sediment accumulation (Gregory and Walling 1973). Geologic investigations of some stream valleys indicate that over the ages the stream channel has been alternately aggraded and degraded, perhaps a number of times (ASCE 1975).

Two types of fluvial deposition result from two different controls: (1) an upstream control related to high sediment production from a source area; and (2) a downstream control related to base level change. Progressive up valley deposition or backfilling of the channel will occur above a dam or wherever base level is raised. High sediment production will overload a channel and aggradation will progressively extend down valley by a process that can be referred to as down filling (Schumm 1977). In cases where tributaries to a main stream provide large sediment supply, both downfilling and backfilling can occur simultaneously in the main channel (Figure 15).

High sediment loads in a main channel can also cause local deposition in the main channel with subsequent backfilling upstream. According to Schumm, this seems to be a dominant process in semiarid and arid regions. A local base level control, caused by the deposition, diverts the flow, reduces the gradient and deposition moves progressively upstream. There can be several sites of deposition of this type in a large valley. The local backfilling above each would eventually produce an overall aggradation in the channel (Schumm 1977).

If the primary mode of sediment transport is suspended load and if the channel is depositing, the major deposition occurs on the banks, causing

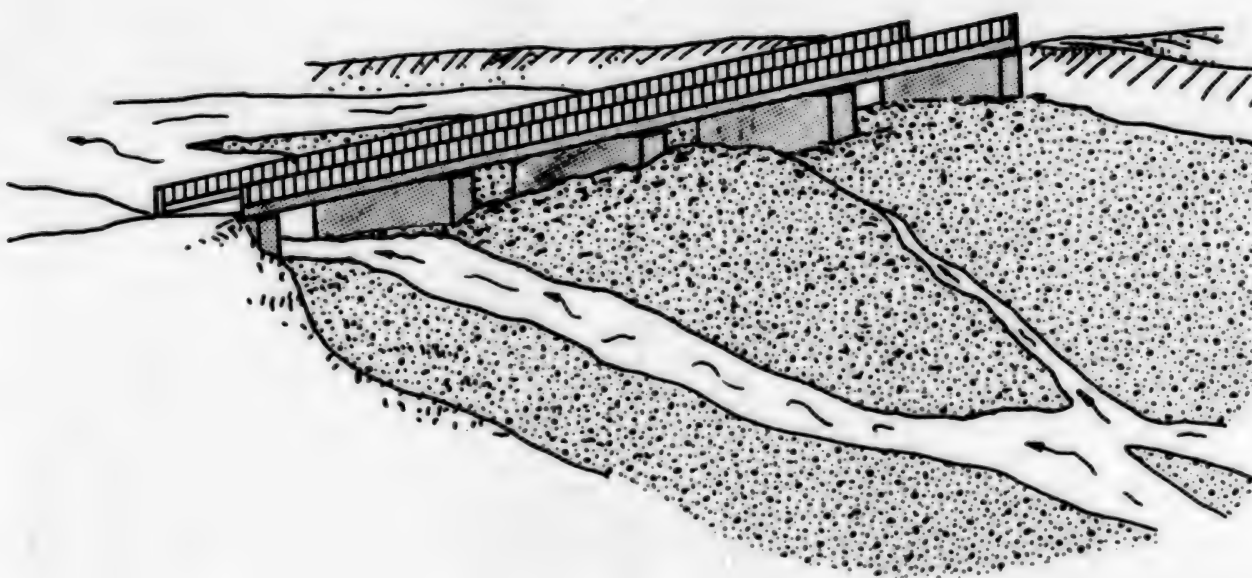


Figure 14. Aggradation commonly occurs upstream of bridge constrictions.



Figure 15. Channel aggradation in the forms of both downfilling and back-filling can occur in the main channel of streams with tributaries which provide large quantities of sediments (confluence of Elk Creek - with highway bridge and Sweetwater Creek with North Fork Shoshone River, Wyoming).

narrowing of the channel or berming and initial stream bed deposition is minor. For a mixed load stream that is depositing, initial major deposition is on the banks, followed by stream bed deposition. For a bed load type stream that is depositing, the deposition occurs on the bed and islands form (Schumm 1977).

It should be pointed out again that there is a big difference in time scale between aggradation and degradation. Based on simplified models of degradation and aggradation, Gessler (1971) evaluated theoretically that the time scale required to complete 95 percent of the degradation process is approximately three times greater than that for aggradation. He concluded that the physical reason for this difference is that, in the end phase of the degradation process, the sediment load becomes very small and subsequently the process requires a lot of time. In the aggradation process, the sediment inflow is constant, resulting in a much faster approach to the new equilibrium conditions. Observations of a river bed made at different times will permit determination of the actual rate condition. The measured sediment load compared to the transport capacity, determined by an appropriate bedload equation, indicates if there is a tendency for aggradation.

Areas of Susceptibility

Areas of susceptibility include sections of river downstream from the sediment producing areas that are either natural or man made. Man made effects include poor farming practices and production of large quantities of sediment through urbanization. Natural effects include gullying and extensive upstream scour of bed and banks. Zones near the confluence of large streams, reaches immediately upstream of reservoirs, and reaches upstream from constricting bridge locations are all susceptible to aggradation (Figure 16). Flow expansion zones downstream of bridges, areas upstream of culverts, and locations where debris accumulates can experience aggradation (Neill 1973). Causes of aggradation may include increase of the base level, regulation of the hydrograph, increase in sediment load, and construction of dikes. Quite often the increase in sediment load is related to some change in the basin, such as reduction of vegetative cover, which leads to erosion and thus to an increase of sediment. Natural causes, such as changes in climate, will only gradually change the controlling parameters, eventually resulting in a slow trend to develop a new river profile. Man's activities will often result in sudden changes in one or more parameters. Geomorphic observations in aggrading rivers show that the river has a tendency to spill over at smaller and smaller discharges (Frenette and Harvey 1973).

Consequences

Aggradation may be more dangerous to a stream system than degradation. It is one of the main causes of reduced channel capacity and overtopping of



Figure 16. Zones near the confluence of large streams and reaches immediately upstream from bridges are susceptible to channel aggradation (Elk Creek near confluence with North Fork Shoshone River, Wyoming).

levees (Simons and Senturk 1977). Increase of sediment load (as by careless land use changes) produces an increase in slope by aggradation, increase in tendency to wander, and increase in width. Adverse effects are liable to occur when a winding natural channel is replaced by a shorter and straighter version of less hydraulic resistance. The consequences may include bed aggradation and increased rate of meandering or channel shifting downstream. In addition to the pattern changes and horizontal instability, the scour and fill of channels also produces major channel control problems. It has been concluded that most terrestrial sedimentation is lateral rather than vertical (Neill 1973).

Accumulation of sediments is the most noticeable effect of channel aggradation on trout habitat. The long term nature of aggradation masks some of the effects. Sediment accumulation, channel shifting, reduced channel capacity, and overtopping of banks or levees are detrimental to trout habitat. The relative instability of habitat in actively aggrading streams hampers stream production in relation to more stable streams. When levees or stream banks overtop, man applies treatments to protect property. Unless properly designed and constructed, these treatments may be ineffective and even worsen the situation. Many treatments applied to aggradation appear to treat symptoms rather than the problem. Construction for these treatments results in both channelization and recurring maintenance problems.

Identification/Photo-interpretation

The study of aerial photographs, particularly wide angle photography, by stereoscopic methods permits recognition of slight relief features, such as those deposits associated with aggrading streams (Thornbury 1969). A persistent trend of raising the stage-discharge curve indicates progressive channel aggradation (Neill 1973). Aggradation is physically demonstrated by the presence of buried lower parts of tree trunks or other fixed reference marks in the channel and/or on the flood plain.

Other photo-interpretive keys indicate the degree of bed material transport and consequent potential aggradation in rivers: (1) few mid-channel bars, regular widths, and bedload assessed to be low; (2) midchannel bars evident, widths variable, and bedload assessed to be important; or (3) many midchannel bars, widths very irregular, and bedload assessed to be more important (Mollard 1973). Aggradation is also indicated by the appearance of sand and gravel bars where they did not previously exist (Pfankuch 1975).

Aggradation is generally considered to be a long term phenomenon measured in years or tens of years. Careful interpretation and comparison of

multidate photography must be made in order to detect the aggradation process. The increased accumulation of bars and the gradual burying of visible land marks, such as trees and structures and other reference points, are interpretive keys. Comparative cross sections, water surface profiles, and bed profiles are important for comparing the rate of aggradation and whether the deposition control is upstream or downstream.

PATTERN MIGRATION

Generally an alluvial river is continually changing its position as a consequence of hydraulic forces acting upon its bed and banks. These changes may be slow or rapid, but it is the rule rather than the exception that banks will erode, sediments will be deposited, and flood plains, islands, chutes, and side channels will undergo modification with time. Meanders swing or shift across the valley and the entire pattern may sweep downstream, resulting in a complete reworking of the flood plain alluvium. The rate at which a single bend migrates and grows depends on its shape and bank stability. Meander growth is at first essentially normal to the axis of the channel, but as the amplitude of the bend increases, downstream shift of the meander becomes increasingly important. Natural, but dramatic changes of river position by cutoffs and erosion are common.

Pattern migration is defined as the natural increase in meander amplitude in the lateral direction and the gradual down valley movement of the overall stream pattern. Only down valley movement of meanders, as described by many writers, seems to occur mainly where meanders are laterally confined (Neill 1973). Lateral and down valley movement of meander bends is a characteristic feature of alluvial rivers and one of the most conspicuous changes affecting fluvial landscapes (Gregory 1977).

Physical Processes

Bank recession rates of 10 to 15 meters per year are by no means exceptional in large rivers, and 100 meters per year is not unknown. Such rates apply to certain bends only. Others on the same channel at the same time may shift more slowly, if at all. Individual bends become distorted and alter their relative position, sometimes so much that they meet and thereby shorten the path of the river through neck and chute cutoffs. The overall meander pattern of the river may be irregular and its details may change from year to year. Local changes may occur wherever or whenever stream flow exceeds the thresholds for erosion of materials composing the banks and bed of the channel (Gregory 1977). Live timber along bank lines should not be removed as the rate of channel migration often increases (Parker and Andres 1976). No live vegetation should be removed or altered anywhere in the floodplain without first considering all potential impacts.

Areas of Susceptibility

All rivers may be separated into two major groups . . . bedrock or alluvial . . . depending on their freedom to adjust their shape and gradient. Bedrock control channels are those so confined between outcrops of rock that the materials forming their bed and banks determines the morphology of the channel. All alluvial channels, on the other hand, are free to adjust cross-sectional shape, pattern, and gradient. They flow through a channel with bed and banks composed of the material transposed by the river under present flow conditions (Schumm 1977).

Horizontal instability of a river may take two forms: avulsion and pattern movement. Avulsion is the sudden shift of the channel from one part of the valley to another by development of a new course; pattern movement can be due to cutoffs that reduce local channel sinuosity or to the growth of meanders. The same river may have patterns ranging from essentially straight to very meandering and even braided (Schumm 1977).

Flow regulation and channelization can accelerate both the pattern and rate of pattern migration.

Consequences

The consequences of pattern migration involving both the natural and man-made effects of lateral and down valley movement of the stream pattern, avulsions, and cutoffs can be most serious depending primarily on the rate of the pattern movement. Slow, steady pattern migration may be entirely acceptable, whereas rapid, intermittent processes may be devastating.

Rapid pattern migration adversely affects trout habitat through erosion and man's attempts to control excessive property loss. Both types of damage to trout habitat are covered under the consequences of gully and bank erosion.

Identification/Photo-interpretation

The identification and prediction of pattern migration is greatly facilitated through the use of photo-interpretation. Color infrared aerial photography is particularly useful for identifying remnants of pattern migration, including cutoffs and avulsion, defining vegetative patterns and types, detecting high velocity flow adjacent to bank lines, and identifying rapidly eroding bank lines.

In looking at pattern migration, care must be exercised in distinguishing between presently active processes and those active at an earlier stage,

but whose traces may be well preserved on the flood plain (Figure 17). Features that assist in this evaluation are meander scrolls, scroll bars, point bar deposits, meander scars, and vegetation patterns (Kellerhals et al. 1976).

Multidate photography is useful for documenting the occurrence and progress of cutoffs, avulsion, and pattern migration. Geology maps and color infrared aerial photography can be used to pinpoint geologic structures that may serve as the limiting boundary for pattern migration.

PATTERN CHANGE (METAMORPHOSIS)

Six subclasses of channels, based on relative stability and the predominant mode of sediment transport, have been established (Schumm 1981). Several other authors have presented river classification schemes (Gaylay et al. 1973; Lewis and McDonald 1973; Neill 1973; Brice 1975; Pfankuch 1975; Kellerhals et al. 1976). River classification based on planimetric form (pattern) directly observable on aerial photography has been developed by Mollard (1973).

River pattern is broadly classed as straight, meandering, or braided. The river planform (pattern) and sinuosity are readily identifiable characteristics on all forms of aerial photography. Stable, suspended-load stream types have sinuosities greater than 2.0; stable mixed load streams have sinuosities ranging between 1.3 and 2.0; stable, bed load streams have sinuosities less than 1.3 (Schumm 1977).

The shifting of a channel across a flood plain is considered natural, and a river behaving in such a fashion should not be considered as unstable. On the other hand, a reach that is changing from high sinuosity to low sinuosity would certainly be considered to have channel instability, even if the change was only local (Schumm 1977).

Physical Processes

Metamorphosis has been defined as a complete change of morphology; that is, a suspended load stream converted to a mixed load or bed load stream, for example. Such changes can occur if the change in discharge and/or sediment load are of sufficient magnitude (Schumm 1977).

Areas of Susceptibility

Basically, river metamorphosis exists as a possibility whenever discharge and/or sediment supply is altered. Any natural or man-made occurrences that alter either the sediment or the discharge characteristics can lead to the metamorphosis process.



Figure 17. Both active and historical pattern migration is visible on aerial color infrared photographs (Green River below Big Sandy confluence, Wyoming).

Consequences

Consequences of river metamorphosis can involve channel aggradation, channel degradation, and lateral migration. The effect of erosion or deposition on channel characteristics is likely to vary widely from stream to stream. It depends on such factors as the size, erosion resistance, and angle of repose of bed and bank sediment, effects of vegetation, the sediment load of the stream, and the magnitude and frequency of the discharge (Gregory 1977).

Assessment of specific effects on trout habitat should consider the processes responsible. Increases in sediment supply have the adverse effects presented under erosion consequences. Decreased sediment production, however, may improve trout habitat in streams which suffer from excessive sediment loads. If extreme flow reductions are responsible for pattern change, different consequences may result. Some Wyoming streams have been affected by diversions and impoundments which eliminate the high, channel forming flows. In extreme instances, channel width has decreased as sediments and vegetation dominate the channel. Similar effects have been documented on the Peace River in Canada (Baxter and Glaude 1980). Flood flows in that river are insufficient to sweep away sediments from the tributaries. Deposits have become stabilized by vegetative growth.

Identification/Photo-interpretation

Multisate photography, coupled with photo-interpretation keys of various stream types, as proposed by Mollard (1973), may be a most valuable procedure for predicting river metamorphosis. Color infrared photography is particularly useful for noting changes in watershed characteristics that may alter the water discharge and sediment production. Change of river pattern from straight, meandering, or braided along a given reach is direct evidence of metamorphosis (Figure 18). Braided channel patterns without instream or riparian vegetative cover have low relative stability; uniformly wide meandering channels without point bars or middle bars and with well vegetated banks are most stable. Any change in flow and/or sediment discharge at a given cross section should be carefully monitored.

DEBRIS

Debris is classified as any material, either floating or submerged, excluding sediment and rocks, that can be or is being transported by flowing water. Debris commonly consists of trees, brush, ice, and man-made products, that might derive from urbanized areas or natural resource development. Floatable objects which accumulate on stream banks and bed commonly



Figure 18. A variety of stream patterns is represented on this stream reach (South Fork Shoshone River, Wyoming). Archival photography or ground observations, however, are needed to determine if pattern change is occurring.

consist of trees and other debris swept downstream by high flood flows (Figure 19). By far the bulk of this debris is natural in origin. Tree trunks, limbs, twigs, and leaves, reaching the channel, form the bulk of the obstructions and act as flow deflectors and sediment traps.

Consequences

Massive debris accumulation generally has detrimental effects on streambank stability and trout habitat. In addition to being a hazard itself, debris can also be a symptom indicative of problems such as severe upstream erosion and poor logging practices. Tree trunks, limbs, and other debris can deflect flows into the stream bank, causing accelerated erosion. Conversely, debris often reduces local velocities and acts as a sediment trap. Aquatic production in riffle areas can be impaired by this sediment deposition. Woody debris collecting on culverts and bridges with short spacing between supports can cause hydraulic problems for the stream and can lead to loss of these structures (Figure 20). Debris removed from structures can cause channel damage if heavy equipment is used.

Severe, direct effects on trout habitat results when debris forms an impassable barrier for trout migrating to or from spawning areas. Debris from logging operations contributes to decreased dissolved oxygen in both surface waters and in water flowing through the gravels (Lantz 1971). Decreased dissolved oxygen levels impair trout survival and reproduction.

Floating ice cakes following spring breakups in rivers of all magnitudes pose serious hazards to the stream bed and bank stability. During the spring ice breakup in rivers of the northern hemisphere, the bed and banks are oftentimes gouged and eroded by ice blocks. Protective armoring, both natural and man-made, of banks and bends, may be disrupted, leading to subsequent high rates of erosion during peak flows. Straightened reaches of channels may be more susceptible to severe ice action during breakup (Neill 1973).

Ice can interfere with intake diversions for water supplies. During breakup, ice can plug channels and cause flooding. Both situations result in emergency instream activities by man which may cause further channel damage.

Effects of debris can, in some instances, improve aquatic habitat. Normally, such improvements do not result from massive debris accumulation. Holding areas for trout can be increased by debris in uniform channels with rapid flows. In strategic sites, debris can deepen pools in shallow streams or provide overhead cover for trout. Removal of floating debris in some instances reduces general stream productivity (Patrick 1973).



Figure 19. Trees are a major form of debris on streams in remote, forested areas (North Fork Shoshone River, Wyoming).

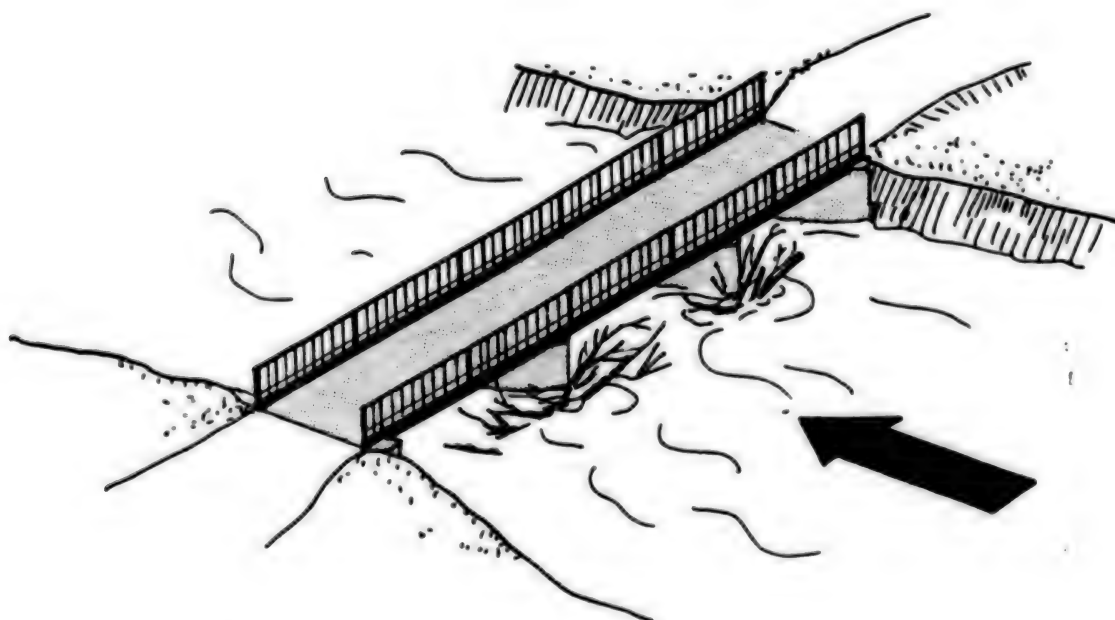


Figure 20. Debris accumulation on bridge piers is particularly hazardous since it reduces flow capacity under the bridge, contributes to upstream aggradation and localized scouring and filling.

Identification/Photo-interpretation

Debris lodged near midchannel or near bank lines where it acts as a deflector can generally be recognized on all forms of aerial photography.

POLLUTION

Next to complete dewatering of the channel, pollution represents the most devastating hazard to trout habitat quality. There are many varieties of pollutants, both man-made and natural, both point and area source, that may be introduced into a stream. Domestic and industrial waste, excessive salt concentration from natural erosion processes on watersheds, and return flows from irrigation practices, represent the common pollutants found in Wyoming.

Even in large river systems, point sources of pollution remain intact as a highly concentrated plume for considerable distances downstream from the point of origin (Figure 21). Mixing and dilution processes for minimizing the impact of the pollutant are often much slower and extend farther downstream than commonly believed.

High concentrations of pollutants are generally found in the vicinity of urbanized areas and regions of industrial complexes, irrigated farming, and natural resource developments.

Consequences

Consequences of pollution have been recognized and documented in many publications. The Federal Water Pollution Control Act of 1965, and subsequent amendments, recognized the important consequences of water pollution. Water quality criteria for fish have been established on a national level initially by the Federal Water Pollution Control Administration (1968) and subsequently by the Environmental Protection Agency (1976), with review by the American Fisheries Society (Thurston et al. 1979). The Wyoming Environmental Quality Act of 1973 and subsequent amendments recognize that fish and other aquatic life, domestic, agricultural, industrial, recreational, and other water users are impaired by water pollution. Under this act, rules and regulations to control pollution have been established. State water quality standards consider the effects of various pollutants on fish. Fishery value is one of the criteria used by Wyoming Department of Environmental Quality (1979) to determine which Wyoming waters should be considered for designation in the most stringent water quality classification (Class I).

Sediments represent the most widespread natural pollutant in Wyoming and possibly other western states. Wyoming fisheries have experienced losses in production, reproduction, growth, and survival from sediments



Figure 21. Turbidity plumes are highly visible on color infrared aerial photographs. Mixing zones are accurately documented (Big Horn River at Fifteen Mile Creek confluence, Worland, Wyoming).

(Binns 1977; Kurtz 1980; Campbell and Hiebert 1981; Mueller 1981). Major effects on trout include egg mortality through interference with embryo metabolism, gill abrasion, reduced production of insects which provide food for fish, and physical covering of riffles which are important spawning areas and feeding grounds. In Montana, high concentration sediment plumes derived from irrigation return flows have destroyed much of the trout habitat and recreation potential in some rivers (Ruff et al. 1973). Sedimentation and associated consequences can be reduced, however, by improved land management practices. Following streambank improvement projects on Bluewater Creek, Montana, suspended sediments decreased by 44 percent. This sediment reduction resulted in a change in the trout: rough fish ratio from 12:88 in 1963 to 51:49 in 1968 (Marcuson 1969).

Identification/Photo-interpretation

Color infrared photography has provided a most useful media for identifying the outfall locations, travel, and impact of a variety of pollutants (Skinner and Ruff 1973). Very slight changes in stream turbidity are recognizable on color infrared aerial photography. This interpretation key allows one to perceive the point of origin, mixing processes, and overall effect on the stream system. Quantitative evaluation of the pollutant and its impact, however, must be performed on-site.

FLOW REGULATION

Control of the flow rate in a natural water course, either by hydraulic structures or man's activities, can lead to critically low water levels for extended reaches of a stream system. Abrupt flow reductions and flow increases through man's activity can have drastic effects upon the fish habitat. Releases from large storage reservoirs, irrigation diversion structures, and return flows, can lead to instabilities of the stream bed and banks, destruction of organisms vital to the fish food chain, and elimination of cover.

Consequences

Flow regulation results in many varied and complex effects on fisheries. Inundation of a good stream segment by a fluctuating impoundment for flow regulation purposes typically results in a net loss of trout habitat. Habitat evaluations of enlargement proposals for Rob Roy and Hog Park reservoirs in southern Wyoming displayed net losses in trout habitat (Miller 1980). Habitat gains from the fluctuating reservoirs with no minimum pool for fisheries were insufficient to compensate for losses from stream inundation. A proposal to build Kendall Dam on the Green River would likewise result in a 42 percent loss in trout habitat units (Binns 1979). Conversely, Grayrocks Reservoir was projected to result in a 176 percent gain in

habitat units over the limited habitat of the lower Laramie River (Binns 1979).

Flow regimes below impoundments or diversions can have drastic effects on fish populations and benthic invertebrates. Most drastic are cases where no instream flow releases are guaranteed. Severe dewatering results in tailwater streams, such as below Guernsey Reservoir in Wyoming, which will not support substantial fish populations. Dewatering from transbasin diversion caused a 74 percent reduction in habitat units on Green Timber Creek as compared to similar, undiverted streams nearby (Binns 1979). Benthos composition, diversity, and standing crops can be significantly affected by upstream impoundments. Whether benthos is enhanced or reduced is largely a result of flow regime (Ward 1976). Kroger (1973) documented that large fluctuations below Jackson Lake Dam resulted in large losses of benthic invertebrates. Mullan et al. (1976) noted that water velocities below Fontenelle Reservoir are too fast for available shelter. That high velocity habitat thus favors trout longer than 12 inches, which are capable of coping with strong currents.

Other effects of flow regulation include physical obstruction of fish passage, increased sediments from operation of flow regulation structures, sediments from dam construction, sediments from breaching unsafe dams (Mueller 1981), and disruption of hydraulic processes downstream. Flow regulation can alter both the pattern and rate of pattern migration. Among the more subtle, but significant effects are degradation and aggradation at the mouths of tributaries from abolition of high flows and formation of bars and deltas on the main stream impounded (Baxter and Glaude 1980). In summary, fisheries effects from flow regulations can be either positive or negative, and site specific evaluations are necessary to even qualitatively determine impacts.

Identification/Photo-interpretation

Aerial photography affords only a one shot view of facilities, structures, and man's activities along a given stream system for identifying sites where flow regulation exists (Figure 22). Constant monitoring of the operation of a given stream system must be maintained in order to ensure proper flow conditions throughout the entire region).

CHANNEL ALTERATION

Channel alterations are defined as any indiscriminate action by man where the natural channel is modified in any way, such as straightening, reshaping the channel crosssection, bulldozing, dredging, unplanned bridge and pipeline crossing, and emergency flood repair (Figures 23, 24, 25, 26, and 27).



Figure 22. Aerial photographs provide documentation of flow regulation structures and can seasonally depict effects of dewatering (Big Horn River near Worland, Wyoming).



Figure 23. Severe channel alteration reduces stream length, impairs trout habitat quality and contributes to property damage both upstream and downstream. This stream is beginning to meander within its channelized boundaries. A recent attempt to force the stream back into a former meander was unsuccessful. Following channelization, the stream channel has degraded below the elevation of its old meanders (Wind River above Dubois, Wyoming).



Figure 24. Aerial view of Figure 23 depicts the magnitude of stream channelization. Former meanders are visible.



Figure 25. Extensive, and largely unsuccessful, channelization has occurred on this stream which suffers from severe channel aggradation. Scars from bulldozer activity document this type of channelization on aerial photographs (South Fork Shoshone River, Wyoming).



Figure 26. Bridges constructed without adequate planning may experience problems at high flows and adversely affect trout habitat. In this example the stream is trying to move back into its old side channel to the right (North Fork Shoshone River, Wyoming).



Figure 27. Channel alterations include emergency work to repair flood damage when highways are threatened (North Fork Shoshone River, Wyoming). Emergency situations make proper project planning and design difficult.

Consequences

Consequences of stream channelization consist of severe adverse effects on fisheries resources and oftentimes on neighboring property. The magnitude of ongoing stream channelization makes this a serious problem. In Wyoming, over 20 miles have been damaged since 1977. This figure is conservative as it is based on observations by Wyoming Game and Fish Department biologists during their general field activities, instead of an intensive survey. The overall stream length affected extends both upstream and downstream from the sites channelized, with the lengths dependent upon stream characteristics and severity of channelization.

Obvious physical features of channelization include straightening, shortening of overall stream length, and removal of streamside vegetation. These result in increased stream gradient and an accompanying increase in stream velocity. Following channelization, streams typically attempt to seek equilibrium with the new hydraulic gradient through erosion and scour. Yearke (1971) documented the effects of channelization which increased the original average stream gradient from 52 ft/mi to 80 ft/mi. This channel adjusted itself to an equilibrium gradient of 70 ft/mi in the seven years following channelization. Erosion triggered by this channelization extended 1,050 feet upstream and 2,100 feet downstream. Maximum horizontal erosion at one point increased the stream from three to four times its original width.

Aside from the subsequent erosion and sedimentation, direct impacts on trout populations and trout food items result from channelization. In southwestern Wyoming, the standing crop of trout in a natural area of the Smith's Fork River was found to be over six times that of a nearby channelized section (Wiley and Dufek 1977). Game fish poundage in natural areas was found by Irizarry (1969) to be 1.4 to 112 times greater than in channelized streams. Alvord and Peters (1963) documented 5 1/2 times as many trout in natural channels than in altered channels. Elser (1968) found that trout were 78% more abundant in natural streams than in altered streams. Although quantification of changes is site-specific, stream channelization in general reduces trout populations. Effects of channelization on fish populations can be long lasting. In a severe case, a 99% reduction in productivity has remained after a 77 year recovery period (Irizarry 1969).

One of the most serious effects of channelization on trout fisheries is the direct loss of stream length (Alvord and Peters 1963; Winger 1972). Such loss usually represents a permanent, complete loss of habitat. Once channelization occurs and the channel degrades below the elevation of former meanders, attempts to put the stream back into its former course are futile (Figure 23 and 24). Channelization can rapidly change the pattern and rate of pattern migration.

Losses to private property often accompany trout habitat losses from channelization. Following channelization of a stream which had experienced lateral erosion of only three feet in the previous 15 years, Baldes (1973) documented the erosion of 137 feet of bank in the next ten years. This loss, totalling four acres of prime agricultural and homesite land, occurred from channelization on only one small section of Big Spring Creek, Montana.

Identification/Photo-interpretation

Unless the channel alteration project lasts over an extended time period, the aerial photography will probably not record the actual construction in time to halt the infringement and complete an impact evaluation. Rather, the photography will record certain key after the fact modification features: equipment tracks; straightened reaches; evidence of new earth work; instream and riparian vegetation destruction; and the new structure, crossing, or repair site. Archival aerial photography again serves well for channel alteration studies.

A PROCEDURE FOR DETECTING HAZARDS UTILIZING COLOR INFRARED AERIAL PHOTOGRAPHY

Color infrared aerial photography provides an effective tool for identifying each of the ten hazards listed in this report. Photo-interpretation keys for each hazard have been provided. Suspect areas, however, should always be verified by on-site visits. There is no substitute for day in, day out, familiarity with the behavior of a stream system. Identification keys for each of the ten hazards also provide the ground observer with methods for positive identification. Color infrared aerial photography provides a way to periodically review the overall stream system from a different perspective, and sometimes processes can be recognized that are either not visible or obvious from the ground.

The use of color infrared film in roll format, commonly in lengths of several hundred feet, requires a light table fitted with some type of film transport system. The supply and takeup reels can be operated mechanically or electrically driven. Particular care must be exercised in using the film so as not to scratch or damage the film emulsion or backing. A duplicate roll transparency should be used as the working copy. A clean, dust free study space, away from bright sunlight, bright artificial lights and reflections, is desirable. A stereoscope or large magnifying glass is helpful, but not absolutely necessary for the level of photo-interpretation work required for this type of study. Space for supporting documentation, including 7 1/2 minute quadrangle sheets, soils maps, geology maps, and land ownership maps is necessary.

Generally, the film is exposed as a single strip taken directly over the river in either a downstream or upstream direction with 60 percent endlap at a scale of 1:12,000 or larger. If a six-inch focal length lens is used, 1:12,000 scale photography provides lateral coverage of about 18,000 feet on 9" x 9" photography. This swath width generally provides adequate coverage of both the flood plain and the adjacent drainage system for most Wyoming streams. When stream alignment requires the aircraft to make a turn to take up a new heading, repeated coverage of the overlap section is desirable to orientate the interpreter.

Archival photography, commonly black and white 9" x 9" prints, is very valuable for change detection of pattern migration, alignment, and sinuosity. A mosaic of the 9" x 9" black and white prints provides a good comparative base to be viewed simultaneously with the color infrared transparencies on the light table. Smaller format photography may also be used by enlarging it to approximately the working scale and constructing a mosaic for use as a reference base. Archival ground photos are very useful for change detection studies.

Information regarding availability and purchase of archival photography, including black and white, true color, and color infrared imagery, is available from the following sources:

U.S. Geological Survey
Rocky Mountain Mapping Center
National Cartographic Information Center
Stop 504, Denver Federal Center
Denver, CO 80225

Remote Sensing
Bureau of Land Management
Division of Operations (941)
P. O. Box 1828
Cheyenne, WY 82001

USDA-ASCS
Aerial Photography Field Office
P. O. Box 30010
2222 West 2300 South
Salt Lake City, UT 84130

National Archives and Record Service
General Services Administration
Cartographic Archive Division
Room 2-W
Washington, DC 20508

In addition to numerous project-related areas of aerial photo coverage, there are two National programs that are presently acquiring photographs for the contiguous 48 states. The National High Altitude Photography Program is acquiring 1:80,000 scale black and white and 1:58,000 scale color infrared imagery. The National Wetlands Inventory Program is acquiring 1:65,000 scale color infrared imagery. Photos from the National High Altitude Photography Program are available from:

U. S. Geological Survey
EROS Data Center
Sioux Falls, SD 57198

After supporting documentation and archival print mosaics have been readied, the interpreter is ready to begin the review of the recently acquired color infrared transparencies in roll format. A tape recorder is useful for making comments about the interpretation as one progresses through the film roll. Several trips through the film roll are often required. First, simply becoming familiar with the coverage is important.

Then the observer progresses from general to specific observations. Finally, another film review after onsite inspection is valuable. There are several easily recognizable general features that one should initially search for:

1. Indication of man's activities in the channel.
2. New instream structures.
3. Stream pattern.
4. Pattern change.
5. Flow alignment changes.
6. Nonvegetated bars.
7. Imminent or recent neck or chute cutoffs.
8. Flow pattern.
9. Instream and riparian vegetation.
10. Water color and concentration plumes.

Man's recent activity in the channel is generally indicated by evidence of construction or equipment tracks. In some instances, the operation may be underway and visible at the time of photography. Any new structure within the stream system, including diversion dams, temporary diversion dams, dikes, crossings, bridges, and roadwork, will alter the regime of the stream both upstream and downstream. Any section with a braided stream pattern is a direct indication of high relative instability. A relatively straight stream pattern is generally not a natural condition and oftentimes a result of man's activities. A meandering stream pattern with well developed bends and crossings, well vegetated banks, and lack of nonvegetated bars, is the most stable pattern.

Pattern change based on comparison between existing and archival photography is a direct indication of stream instability. Flow alignment changes caused by development of new bars or islands or a change in the direction of the flow pattern due to debris or other obstructions can lead to rapid pattern migration or localized bank erosion. New, nonvegetated point bars, middle bars, or alternate bars, are direct indicators of active bed material transport and/or bank erosion. These generally show up as bright deposits and are easily recognizable within the mainstream. Recent or imminent neck or chute cutoffs identify locations where rapid changes occur or

will occur. Water surface texture enhanced by reflections provides the interpreter with information about flow pattern, flow concentrations along bank lines, and the position of the thalweg. Constant monitoring of the changes in instream and riparian vegetation is of the utmost importance. Reduction of vegetation indicates that instability problems are about to follow. The clear water conditions show up as black on color infrared aerial photography, whereas slight increases in suspended material concentration produce a progressively lighter blue color to the water. Very slight changes in the suspended material concentration produce contrasting color between the plume and the receiving water. The ability to monitor slight suspended material concentration changes in rivers is one of the most useful aspects of color infrared film.

After the interpreter has become familiar with the stream coverage and identified and recorded any general instability features described above, the next step is to go to the more specific identification of each of the ten listed hazards. Photo-interpretation keys for each of the ten hazards previously listed are summarized below:

<u>Hazard</u>	<u>Key Indicators</u>
1. Gully Erosion	a. Steep-sided valleys adjacent to cultivated upland or overgrazed pasture land. b. Characteristic drainage pattern and cross sectional shape of the gully depending on the type of soil. c. Gulch development off of terraces or benches. d. Light-colored gully walls and lack of vegetative cover about the perimeter of the gully. e. Lush vegetation may exist in the bottom and at the extreme upper end of the gully where some water may accumulate.

<u>Hazard</u>	<u>Key Indicators</u>
2. Bank Erosion	a. Flow concentration along concave bank lines or through constrictions evidenced by water surface roughness enhanced by the sun's reflection. b. Tipping or falling trees adjacent to the bank line. c. Nonvegetated point bars immediately downstream from regions of eroding bank lines. d. Irregular or ragged bank line. e. High banks indicated by shadows. f. Flow paths deflected directly into or against the bank. g. Cracks along the bank surface, slump blocks, and fresh vegetation laying in the flow. h. Increased turbidity downstream from the eroding area and fresh vertical or sloping face cuts. i. Deep scour pools adjacent to the toe of the bank slope. j. Evidence of slope instability on adjacent hillsides. k. Ground water seepage areas.
3. Channel Degradation	a. Nonvegetated middle bars immediately downstream from the degrading area.

Hazard

Key Indicators

b. Evidence of undermining of structures or exposed tree roots or high exposed banks.

c. Man-made or natural drop in base level of the stream.

d. Areas downstream of newly constructed diversion works.

e. Extensive reaches of bank caving.

f. Regions of channel straightening.

g. Sections of man-made cutoffs.

h. Reaches of entrenched channels.

4. Channel Aggradation

a. Nonvegetated middle bars.

b. Evidence of stream avulsion (jumping out of banks).

c. New lateral flow patterns visible.

d. Evidence of burying of structures and tree trunks.

e. Visible evidence of extensive sedimentation in the main channel or zones near the confluence of streams.

f. Reaches upstream of reservoirs and constricting bridge locations.

g. Raising of the base level by either natural or man-made activities.

Hazard	Key Indicators
5. Pattern Migration	h. Increased wandering of the stream.
	i. Increase in stream width.
	j. Pattern change.
	a. Comparison with archival photographs, preferably enlarged to the scale comparable to the film being interpreted.
6. Pattern Change	b. Areas of juvenile meanders or recently straightened reaches.
	c. Areas where recent or imminent neck or chute cutoffs occur.
	d. Sudden shifts caused by avulsion. (In alluvial flood plains, the color infrared film shows where the stream has been during the recent past and can be expected to migrate to any position within that flood plain in the future. Geology maps are useful for pinpointing the "hard rock" control points that limit the migration of the pattern).
	a. Archival photography must be utilized to identify pattern changes along a given reach of stream system.
	b. Braided patterns, in general, indicate very unstable reaches, resulting in high bed material transport, active bank erosion, active pattern migration, and channel aggradation.

Hazard	Key Indicators
7. Debris	a. Large trees and brush accumulating on bars, on bridge piers, along bank lines, and in shallow water areas. b. Evidence of equipment use for channel clearing.
8. Pollution	a. On color infrared aerial photography, any water color other than black indicates evidence of suspended material. Note, however, that in some instances the bottom of shallow, clear, water areas will be visible. b. Pollution plumes are highlighted by slight color contrasts. Water color changes require on-site visits to identify the source, type, and concentration of pollutant.
9. Flow Regulation	a. Presence of dams or diversion structures. b. Evidence of dewatering indicated by standing pools of water and exposed bed and banks.
10. Channel Alteration	a. Evidence of equipment tracks within the main channel. b. Evidence of straightened reaches. c. New dikes or diversion structures. d. Instream or riparian vegetation modification.

TECHNIQUES FOR MITIGATING HAZARDS

The identification of general instability features and/or any one or more of the ten listed hazards obligates the observer to promptly find ways to remedy the problem. Several procedures are being used successfully in Wyoming at the present time to eliminate or reduce the impact of some of the ten listed hazards. Recommendations or successful practices being utilized by other states are given in some instances.

<u>Hazard</u>	<u>Mitigating Technique</u>
1. Gully Erosion	Grazing control, vegetation improvement, riprap at the head of the gully, cross channel cribs, stabilization of the bed and banks, and site specific gully erosion control structures.
2. Bank Erosion	Tree revetments (Figures 28, 29 and 30), brush revetments (Figures 31 and 32), bank sloping (Figure 33), fencing to control grazing (Figure 34), car bodies (Figures 35 and 36) which have been commonly used in the past but are <u>not</u> recommended, and large rock riprap (Figure 37).
3. Channel Degradation	Base level control, natural armoring of the bed.
4. Channel Aggradation	Eliminate constrictions and expansions where sediment deposits are excessive, stabilize upstream bed and banks to eliminate sources of excessive sediment supply.
5. Pattern Migration	Control bank erosion, encourage deep-rooted riparian and instream vegetation.
6. Pattern Change	Minimize changes in sediment or water discharge characteristics.



Figure 28. Tree revetments are effective in halting bank erosion and providing trout habitat (Little Popo Agie River, Wyoming).



Figure 29. Logs and dead trees provide bank protection in some instances (Green River near Pinedale, Wyoming). They may cause debris or other problems if dislodged or situated such that flow is diverted toward the bank.



Figure 30. Even properly anchored floating logs with few limbs can protect against further bank erosion and provide trout habitat. In this example, erosion was threatening an irrigation canal (New Fork, River, Wyo.).



Figure 31. Brush revetments held in place by metal pipe effectively controlled bank erosion near an irrigation diversion structure (Green River near Pinedale, Wyoming).



Figure 32. Failure to extend brush revetments (or any bank protection) far enough results in bank erosion immediately below (Green River near Pinedale, Wyoming).



Figure 33. Bank sloping effectively controlled bank erosion but also eliminated trout habitat (New Fork River, Wyoming).



Figure 34. Vegetation effectively retards bank erosion as evidenced by this area where grazing was controlled by fencing (Green River near Pinedale, Wyoming).



Figure 35. Car bodies have, in some instances, retarded bank erosion. In many instances, however, placement of bodies has worsened the problem. Because of this and their unsightly appearance, car bodies are not recommended. (Green River, Wyoming).



Figure 36. Landowner installed bank protection projects can be quite effective and improve trout habitat if properly constructed. The landowner in this example installed three car bodies, filled over them and revegetated the site. Only part of one car body is visible (Little Popo Agie, River, Wyoming).



Figure 37. Proper use of large rock riprap can control bank erosion and improve trout habitat (Wind River near Dubois, Wyoming).

<u>Hazard</u>	<u>Mitigating Technique</u>
7. Debris	Control bank erosion, monitor and control watershed practices that produce debris, remove debris selectively.
8. Pollution	Erosion control. Good watershed and riparian zone management and legislation, point and nonpoint source monitoring and control.
9. Flow Regulation	Cooperative relationships with operators of hydraulic structures to control both the discharge of water and sediment, and legislation which allows maintenance of instream flows. Refined water management to prevent unnecessary, periodic, extreme dewatering and diversion in excess of needs or rights. Planning considerations in the development of water projects, timing, location of diversion, construction techniques (cofferdams instead of total stream diversion) at bridges and pipeline crossings to avoid dewatering.
10. Channel Alteration	Education, legislation, and detailed design planning and cooperation performed jointly by aquatic biologists, engineers, landowners, and other interested parties.

CONCLUSIONS

1. Bank erosion was the most prevalent hazard found in the study. All ten hazards were identified in Wyoming during the summer of 1981.
2. Hazards can be identified from color infrared aerial photography and verified by on-site visits.
3. Causes of hazards are sometimes more evident on the color infrared aerial photograph than on the ground.
4. The hazards can be mitigated through cooperative efforts, design, and control of natural processes.
5. Reaches with poor fish habitat can be improved through detailed design.
6. If a hazardous condition goes unchecked, it can produce a serious instability problem that extends both upstream and downstream for considerable distances. Such problems affect water quality, stream condition, and streamside property, in addition to trout habitat quality, thus affecting all users.
7. Site specific variations in extent and types of hazards, geography, geology, hydrology, availability of materials, land use, fisheries values, and numerous other features preclude formulation of a general cookbook approach to mitigating individual problems. Interdisciplinary approaches are recommended for mitigating individual problems.
8. Interpretative keys, mitigation techniques, and the hazards themselves, are applicable to other western states, although the study was specific to Wyoming.
9. The general public must be made aware of the many hazardous conditions that exist and that something must be done in order to prevent irreparable damage to the system. This requires persistent monitoring, educational programs, and legislation in some instances.

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